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THE SUBDIVISION OF THE REPRESENTATION OF CUTANEOUS AND MUSCULAR SENSIBILITY AND OF STEREOGNOSIS IN THE CEREBRAL CORTEX.*

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The main object of the present contribution is to present the following propositions: (1) that the cortical representation of cutaneous and muscular sensibiltiy is independent of motor representation, that it surrounds the motor zone, and that it is subdivided into a mosaic of centres, each centre or group of centres being anatomically and functionally correlated to a motor centre or centres; (2) that every muscle or group of muscles producing a movement or movements which are represented by separate centres in the cortex is topographically related to a segment of the skin which has also a definite cortical centre, this centre being correlated anatomically and functionally with the motor centre; (3) that stereognostic representation like that of cutaneous and muscular sensibility and of movements has also its independent cortical area, and is subdivided after the manner of the motor and sensory areas.

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It will be seen that according to the above propositions, the representation of cutaneous and muscular sensibility and stereognosis is not only for the face, arm, trunk, and leg, but for subdivisions of these parts.

The acceptance of the view that the motor zone is entirely cephalad of the central fissure gives a position of advantage in discussing the question both of separate motor and sensory representation and of the subdivisions of the latter. Those who believe that the cortical motor and sensory areas are identical have until recently been in the majority, but the weight of opinion is now in favor of the separatists.

The writers accept without qualification the view that the motor area is cephalad of the central fissure. One of them (Dr. Mills) has been a consistent advocate of separate motor and sensory representation. As early as 1888 he attributed sensory functions to the parietal lobe, and also in several publications (1888, 1895 and 1904)[1] expressed the view that the cortical sensory area was subdivided into centres in a manner similar to the subdivision of the motor area.

The following quotation from the paper published in 1904 gives his views as then expressed:

"It is probable that the areas of representation of cutaneous and muscular sensibility are subdivided in a manner analogous to the subdivision of the motor area, in other words, for the face, head, neck, upper extremity, trunk, lower extremity and other parts of the body, and that even some of these areas contain subareas and centres. As indicated diagrammatically, the cutaneomuscular sensory area encircles on all sides the great motor area on the lateral aspect of the hemispheres, occupying the postcentral convolution and the anterior extremities of the superior and inferior parietal gyri or lobules, and on the mesal aspect the more posterior and inferior portions of the paracentral and frontomarginal gyri, and the contiguous parts of the precuneus and gyrus fornicatus. The sensory areas for the face, head, neck, upper extremity, trunk, lower extremity, etc., occupy respectively areas adjoining the subdivisions of the motor cortex representing these parts of the body; in other words, that the areas and subareas of representation of the movements of the larynx, jaws and face should be toward the lowermost portion of the postcentral and postparietal convolutions, the areas for the head and neck, upper extremity, and trunk coming next in order from below upward, while on the lateral edge of the hemisphere and on its mesal aspect are centres for the lower extremity, anus, genitalia, and viscera. Clinicopathologic, experimental and psychologic facts can be adduced in support of these localizations. Studies in hypnosis, and in hysteria and of the sensory aura of Jacksonian epilepsy point in the same direction. A considerable number of cases of limited cortical or of subcortical lesion have been recorded in which the anesthesia has been circumscribed to a limb or the face or trunk, or to special portions of these larger divisions of the body. The well-known experiments of Horsley and Schäfer also showed that circumscribed areas of anesthesia sometimes resulted from experimental lesions of the limbic lobe. Grünbaum and Sherrington, in their experiments on the higher anthropoids, demonstrated that certain segments of the non-excitable postcentral convolutions were distinctly related to particular subdivisions of the precentral motor cortex. Faradization of portions of the cortex of the postcentral convolution, while not calling out motor response, facilitated this response in portions of the precentral convolution at the same horizontal level. This is a fact pregnant with suggestion."

At a meeting of the American Neurological Association, held in St. Louis, September 15, 16, and 17, 1904, Dr. Mills presented a paper on the location and subdivision of the cortical areas of cutaneous and muscular sensibility. This paper, however, has never been published, and some of its data have been incorporated in the present article.

The view that an area jointly sensory and motor is subdivided into centres of special representation for different portions of the body (Dana, Starr, Horsley and others) must not be confounded with that which holds in the first place, that the areas of representation of movements and of sensibility and of stereognosis are separate; and secondly, that these are subdivided into subareas and centres. It is the latter doctrine which is taught in this paper.

The evidences which favor the subdivision of the sensorial and stereognostic cortex are chiefly clinical cases with or without necropsy in which this subdivision is indicated. The experimental and histological data with regard to cortical motor and sensory localization up to the present time, chiefly have reference to the position and extent of the zones of representation and not to their subdivision. The clinical and clinicopathological cases are of two kinds: those in which symptoms indicate both motor and sensory subdivisional representation and those in which sensory representation alone is illustrated.

We shall not recall here those cases now well known in neurological literature in which both motor and sensory subdivisional localization are indicated, that is, cases in which both loss of power and impairment of sensation were confined to a leg or an arm, or the face or to subdivisions of these portions of the body. These cases are scattered through the literature of the last twenty-five years, and most of them are to be found in the elaborate digests of cases published by such writers as Starr[2], Dana[3] and Verger[4].

Dana, in discussing the cases collected by him, said that the anesthesia was always circumscribed to the face or limbs or to a special part of the body; it was never complete hemianesthesia when the lesion was cortical. The sensory centres for various parts of the body, as for the face, arm and leg, were however according to him, commonly identical with the motor centres for those parts, but were larger and more diffused. Starr held to a similar view.

We shall now call attention to a series of cases, comparatively few but important, which seem to indicate a large degree of subdivision of the areas of representation of cutaneous and of muscular sensibility and of stereognosis. In the presentation of these cases those first given point only to the subdivision of the cortical areas of representation of cutaneous and muscular sensibility. The later cases indicate that the stereognostic zone is similarly subdivided. In considering the first cases (Knapp, Darkschewitsch, Madden and Starr and McCosh) it must be remembered that they were recorded before the subject of stereognostic conception and astereognosis had been considered in neurological literature. In some of them, therefore, it is probable that astereognosis, as well as impairment of cutaneous and of muscular sensibility, was present.

A case recorded by Knapp[5] in 1891 is confirmative of the subdivisional sensory representation in the cortex and might also be regarded as evidence in favor of the separate cortical representation of movements and of sensation, as the lesion was presumably behind the central fissure. The most interesting fact in the present connection is that the loss of cutaneous sensibility involved only the hand and forearm. This case was one of traumatic brachial monoplegia with limited loss of sensation. The patient had received a wound on the head during the Civil War and was operated on about thirty years afterwards. During the operation the surgeon injured the cerebral cortex in what was supposed to be the middle portion of the left postcentral convolution, the lesion being recorded as about one centimeter long and about three millimeters in depth. The results of this surgically produced lesion were disorders of sensation, which continued while the patient remained under observation. They are recorded as having been present at the end of the year. Tactile sensibility was much diminished in the right upper extremity; the patient had no consciousness of the position occupied by the extremity; muscular sensibility was lost in it. The sensations of pressure and weight were also lost, but pain and temperature senses appeared to be normal. The loss of cutaneous sensibility extended only to the elbow.

Darkschewitsch[6] recorded a case in which general sensibility was entirely diminished in all its forms in the right upper extremity, and especially in its periphery. Sensibility was unaffected in the right leg and right side of the face, and these parts also presented no affection of motility. At the necropsy a solitary tubercle was found in the white substance of the left cerebral hemisphere, subjacent to the cortex of the middle portion of the postcentral gyre. It will be seen that this lesion corresponded closely to what we regard as the subarea of cutaneous and muscular sensibility for the right upper extremity.

Madden[7] recorded a case of cortico-subcortical tumor with apoplectiform attacks preceded by a sensation of pressure, with incoördination of the arm and forearm of the left side followed by paralysis of the leg and arm of the same side. Examination showed that on the left hand tactile sensation was much altered and that it was completely lost in the ring finger. The muscular sense was also lost, and at times there was marked ataxia. The disorders of sensibility became more and more apparent as time advanced. At the necropsy a prominence, thinning of the dura and depression of the cranium were found on the left side at a point half an inch to the left of the longitudinal sinus in the postcentral gyre. Symmetrically situated on the opposite side was a smaller prominence. Underneath this prominence was found a cystic tumor which involved the postcentral, the superior parietal, supra Sylvian, and the inferior portion of the angular and occipital convolutions.

Starr and McCosh[8] reported a case in which, for the relief of spasmodic attacks, trephining was performed and a small angioma removed. The operation was followed by loss of muscular sense in the opposite hand and forearm without any disturbance of other sensations or of movement. There was also marked ataxia in this limb. The place of operation corresponded to a spot about the junction of the superior and inferior parietal convolutions, and distinctly posterior to the postcentral convolution.

In a case reported by Klien[9] of trauma of the left side of the skull, in which the injury was supposed to have involved both the precentral and postcentral convolutions, there was a resultant paresis of the right side of the body. Sensation for light touch was diminished over the whole right side, but touch applied a little more deeply was disturbed only in the right arm. This was especially so in an irregular area over the radial side of the right hand and forearm. The pain sense was disturbed over this same area, but temperature sense was somewhat altered over the whole right side. The sense of position and stereognostic conception were disturbed in the whole arm, and there was considerable ataxia of this arm.

Bonhoeffer[10] in a study on disturbances of sensation due to cortical lesions, reported a case (case 4) in which, because of a depression of the right parietal bone, paresis of the left arm, and especially of the hand was present. Sensation for pain was diminished over the whole left side, but especially so in the upper limb. The sense of touch, of localization, of motion, and of position, and stereognostic conception were impaired over the whole hand, but especially so in the third, fourth and fifth fingers.

Fischer[11] reported a man of twenty-three years, who because of numerous cysts in the cerebral cortex, had attacks of Jacksonian convulsions, which always began with a feeling of numbness in the fourth and fifth fingers of the left hand. The patient was operated upon in the right motor area and a cyst due to a cysticercus was excised. The patient improved, but subsequently the Jacksonian attacks reappeared.

When examined by Fischer sensation for touch and pain was lost in the three ulnar fingers and in the ulnar side of the hand both in the palmar and extensor surface up to the wrist. From here to the elbow there was hypesthesia for touch and pain. This sensory disturbance faded imperceptibly into the surrounding parts. The sense of localization, of movement, and of position, and stereognostic conception were lost only in the fourth and fifth fingers. Power was little if at all disturbed in these parts. Several days after the examination giving the above results, a complete hemianesthesia for all forms of sensation was obtained, and other symptoms regarded as hysterical were also found. Suggestive treatment removed the sensory disturbance, and because of this the ulnar disturbance of sensation was regarded by the author as hysterical in origin.

It is probable that the disturbance of stereognostic conception and of other forms of sensation in the ulnar side of the hand was of organic origin, and that the subsequent hemianesthesia was due to a superimposed hysterical condition.

Kramer[12] in 1896, in a paper on "Tastlähmung" or touch paralysis, reported a number of cases of localized disturbances of sensation due to cortical lesions. Among these, in one case (case 6), a man of forty-two, after a sudden attack of dizziness, developed weakness of the left upper limb with increased reflexes. Sensation in the left hand for touch, for pain and for temperature was normal. On the third, fourth and fifth fingers, however, there were very mild disturbances of sensation of touch as well as of the sense of localization. The sense of movement was disturbed in the second and third fingers.

In a paper on the sensory disturbances occurring in hemiplegia Sandberg[13] reported a number of cases of localized disturbance of sensation. In one case (case 1) a man of forty-five, with a history of Jacksonian convulsions limited to the left side of the body, and beginning in the left face, when seen some years after the spasms were noted, showed no motor involvement anywhere. The reflexes were normal. Touch-sensation was somewhat disturbed, especially in vola manus, as well as in extensor surface of the hand. Sensation for temperature and for pain was normal. The pressure sense was disturbed in the whole hand.

The sense of movement as well as the sense of localization and stereognostic conception were disturbed somewhat in the whole left hand and especially so in the third, fourth and fifth fingers. Sensation in the right side was normal.

Of the nine (9) cases thus briefly abstracted, only in those in which necropsies were had or in which the operative procedure indicated clearly the site of the lesion, can it be said with positiveness that the lesion was entirely behind the central fissure. Apparently it was behind in at least five of the cases. In all the lesions were in part at least behind the fissure.

The cases are particularly interesting as indicating the limitations of anesthesia and astereognosis, not only to the upper extremity, but to limited portions of this limb, and especially to the hand and certain of the fingers.

The impairments of sensation present were in several instances more or less dissociated, certain forms of impairment being present and others not, or different forms showing themselves in different parts.

It is interesting to note that in four of the nine cases the impairment and disturbance of sensation were greater in the fingers towards the ulnar side of the hand, this showing itself sometimes in two and sometimes in three fingers.

The cases clearly indicate the subdivisional representation in the cortex, and most of them that this subdivisional representation is for definite portions of the extremity, as for certain fingers or for the ulnar or radial portions of the hand.

To these nine cases we shall add four studied by ourselves.

Case 1.—*Traumatism and syphilitic meningitis of the parietal lobe; Jacksonian epilepsy beginning in the fingers and hand; astereognosis in the left hand; tactile anesthesia and impairment of pain sense in the left upper and lower limbs; operation for removal of diseased mass from the parietal region; transient paralysis after operation with persistent sensory loss and astereognosis; objects recognized by the left thumb and forefinger, but not by the other fingers, which showed greater impairment of sensation and of co-ordination; second operation and further removal of diseased tissue; astereognosis, ataxia, and impairment of sensation now the same in all parts of the hand and fingers; necropsy showing widespread gummatous meningitis and an area of softening in the postcentral and inferior parietal convolutions, to a very slight extent invading the precentral convolution.*

This patient was a man of 41 years, who for four years had been under our observation either in the Polyclinic, the Philadelphia General, or the University Hospital. He had been at various times under the care of Dr. Wm. G. Spiller. He was not married and admitted a specific history. He had been a hard drinker and five years before he first came under our observation, while having a fight in a saloon, was thrown out into the middle of the street, and was taken to the Pennsylvania Hospital, where it was said that he had concussion of the brain. He was unconscious for about twenty-four hours. Four years after this, while again drinking, he fell backwards and struck the back of his head on a brick sidewalk. His head was cut in the parietal region a little to the left of the median line.

When he first came to the dispensary of the Polyclinic Hospital, April 29, 1902, examination showed the right side of the head to be more prominent in the parietal region. About 9 cm. (3.54 in.) above the attachment of the ear to the head was a depression in the bone about the size of a little finger. This area was very sensitive to pressure. Dullness was obtained over this part. The patient dated his headache from this accident, it being frontal and persisting night and day. He also had what he called sharp neuralgic pains. At times he vomited after eating and he also complained of nausea.

On Feb. 3, 1902, he had his first convulsive attack. This began with pain in the tips of the fingers of the left hand; then passed to the back of the hand, and according to his description, his fingers were twisted in every shape. The convulsion then crept up his arm, the patient experiencing pain in the top of the left shoulder, after which he lost consciousness, frothed at the mouth, but did not bite his tongue nor void urine. His arm was not weak after the attack.

When examined, station and gait were normal, the eyes both as to condition of the pupils and extra-ocular muscles were normal, and sensation was normal all over the body. The reflexes were also not altered except the right patellar jerk which was slightly increased. Even at this time he called a quarter a five cent piece in the left hand. Motor weakness was everywhere absent.

From this time until his admission to the Polyclinic Hospital, April 29, 1902, he had several convulsions, all of which were similar in character to the first, except that they became longer. He would at times complain of pain as if an electric shock would start in his hand and travel from the finger tips to his forearm and arm, and his fingers would feel cold and numb after the attacks. On his admission to the hospital examinations showed that the grip of the left hand was not as strong as that of the right, and that he could not recognize any object placed in the left hand.

Five days before the operation was performed upon him examination by Dr. Spiller showed complete loss of stereognostic conception in the left hand and complete tactile anesthesia and impairment of the sense of pain in the left upper limb. Sensation for touch and pain was also diminished in the left lower limb. The reflexes in the left upper and lower limbs were increased, but not markedly exaggerated. Ankle clonus and Babinski response were absent on this side. Sensation and the reflexes on the right side were normal. The sense of position in the left arm was lost and was impaired in the left leg. The eye examination did not show anything abnormal except a slight paleness of the left optic disc.

The examination of the patient, five days later, just before the operation, showed almost complete paralysis of the left upper limb, the patient being in a mild stupor, although able to answer questions. Sensation seemed about the same as in previous examinations.

Dr. John B. Roberts, under complete anesthesia, operated over the right parietal bone, and after dissecting up an oval flap he found a spot of carious bone about the size of half a dollar. This was easily removed by bone forceps. The dura was thick and was cut away, exposing a hard mass about the size of a pigeon's egg, with several small nodules attached. A part of this mass was brain substance.

The patient made a good recovery. Examination several days after the operation showed almost complete paralysis of the left upper limb and some paralysis of the left lower limb. Tactile sense was almost entirely lost in the left upper and lower limbs, pain and temperature senses were only slightly impaired in the left upper limb and preserved in the lower limb, the sense of position was lost in the fingers and toes on this side. The reflexes were exaggerated, but there was no Babinski response. About three weeks after the operation the man left the hospital. The paralysis in the left upper limb had almost completely disappeared, the return of voluntary power being remarkable in view of the complete paralysis which existed previous to the operation, and the fact that considerable brain tissue had been removed. Stereognostic conception was completely lost in the left hand and there was still some impairment of sensation in the left upper limb.

The miscroscopical examination of the specimen removed at the operation showed intense inflammation and round cell infiltration, suggesting syphilis and gumma of the cortex.

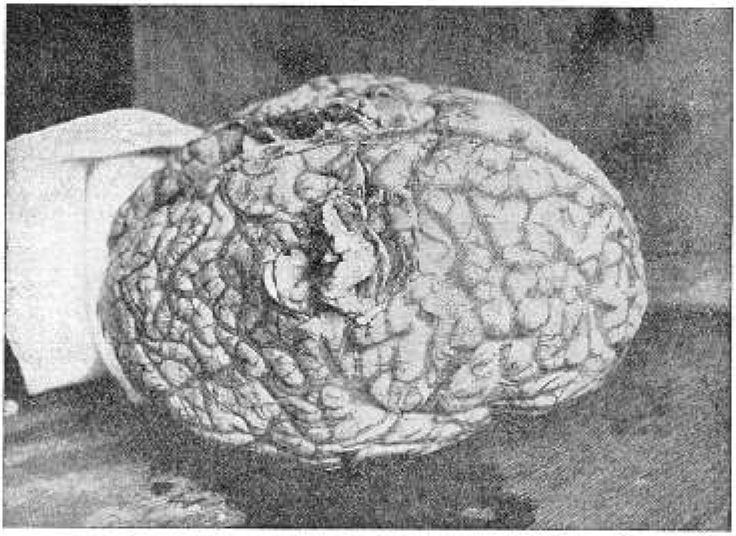
For six months after the operation the patient was well and he had no convulsions. He was completely free from headache, nausea and vomiting. He had, however, in the meantime resumed his previous alcoholic habits, and he had not been regular in his taking of potassium iodide, which was given to him after the operation. About six months after his operation he began again to complain of convulsions, and these were similar in character to those previously described. When examined, March 9, 1903, about nine months after the operation by Dr. Weisenburg, the patient complained of considerable persisting frontal headache, nausea and vomiting. His gait and station were good. The grip of the left hand was weak, this being the only sign of motor involvement. Sensation for touch and for pain was disturbed over the left upper limb, and somewhat in the left lower limb. The reflexes were generally increased, but were more so on the left side. He called attention to the fact that he was able to recognize objects placed between his left thumb and forefinger, but could not recognize any object in his other three fingers. Examination confirmed this fact. He stated that he had had this condition since his recovery from the operation. A further examination showed that the sense of position was lost entirely in the three ulnar fingers, but was preserved in the thumb and forefinger. Sensation for touch and for pain was also disturbed more in the ulnar three fingers and less so over the skin covering the thumb and forefinger and the radial side of the hand. In the finger to nose test considerable ataxia was apparent and this was also more marked when the ulnar fingers were directed to the nose.

He constantly complained of an agonizing pain in the left upper limb; in fact, he came for treatment principally because of this and his convulsions. He stated that his left upper extremity constantly felt as if it were being cut by a knife or as if he were having a convulsion. These pains existed for over two years, until the time of his death. Towards the latter end of his life he would also complain of pain in the lower limb and sometimes in his face, chest and abdomen, but mostly the pains persisted in the left upper limb. The convulsions would always start in the left upper limb. During these the pains would become excruciating. During most of the convulsions he would not lose consciousness.

Because of the increase of headache, nausea and vomiting, and the increasing number of convulsions, he was admitted to the University Hospital and was again operated upon, this time by Dr. C. H. Frazier, on Oct. 15, 1904. In the operation the incision followed the line of that made at the original operation. The scalp and dura seemed more or less fused together and the dura was adherent to the substance beneath. After the dura was opened, grayish tissue was found beneath and scraped away. The brain was much congested. Gummatous tissue was also scraped away from the inner side of the dura.

The patient was not much benefitted from the operation. The convulsions were just as marked and the pains just as severe. He had, however, some relief from his headache, nausea and vomiting.

Ophthalmoscopic examination at no time revealed anything but a slight paleness of the optic discs of both sides. The convulsions now, instead of always starting in the fingers of the left upper limb, would sometimes start in these and again in the abdominal muscles of the left side. The patient's condition grew gradually worse, the convulsions became more frequent and the pains of such intensity that he had to be kept constantly under the influence of narcotics and hypnotics. Examination just before his death showed some weakness of the left upper limb, but none of the face or of the lower limb. Sensation for touch, for pain, and for temperature was disturbed over the left upper limb and less so over the left lower limb.



Photograph of Brain of Case I. Area of Softening Involving Part of the Upper Portion of the Postcentral Convolution and the Anterior and Superior Portions of the Inferior Parietal Convolution. A Little of the Precentral Convolution Was Also Involved.

Directly after the operation by Dr. Frazier it was noted that he was unable to recognize objects placed in his whole hand, whereas previous to the operation he could do this between his thumb and forefinger. The loss of the sense of position, the ataxia, and the impairment of sensation all seemed to be equally marked in all portions of the hand. The patient died about Jan. 1, 1906.

Necropsy was performed by one of us (Dr. Weisenburg). The scalp over the right side of the skull was adherent, especially over the site of the operations, and had to be dissected away. The right portion of the skull was exceedingly carious and was cut away without much effort. The bone and the dura were adherent almost over the whole surface of the brain, but especially so over the right side where it had to be dissected away. On removing the skull a thick gummatous meningitis was found, this being marked over both hemispheres, but especially so over the right hemisphere. Over the right parietal area it was at places almost a quarter of an inch thick. When removed, an area of softening was found over the right parietal lobe. This area, as indicated in the photograph, (Fig. 1) involved part of the upper portion of the postcentral convolution, a very little of the adjacent precentral convolution, and the anterior and superior portions of the inferior parietal convolution. The microscopical examination showed typical syphilitic exudation.

A careful examination of the spinal roots of the fourth, fifth, sixth, seventh and eighth cervical and first thoracic segments of either side showed no round cell infiltration. The roots were cut separately.

Case 2.—Parietal injury with unconsciousness; ataxia, loss of the sense of position, astereognosis, and impairment of the senses of touch, pain, temperature and spacing in the hand and upper extremity; later cutaneous sensibility, the senses of position and of movement, and stereognostic conception better in the thumb and forefinger and radial side of the hand and forearm than in the other fingers and ulnar side; touch and pain senses were more disturbed in the distal than in the proximal portions of the hand; pain sense more appreciated in the palmar than the dorsal surface.

The history of this patient was given by Dr. Spiller in the Feb., 1906, number of the JOURNAL OF NERVOUS AND MENTAL DISEASE, in a paper on separate sensory centres in the parietal lobe for the limbs. We will first give his account of the case, somewhat condensed. A man, 38 years old, was struck over the right parietal lobe with a club on July 21, 1904, was unconscious for one or two hours and was confined to his bed about ten days after receiving the blow. For two weeks he could not move the fingers of his left hand, either as the result of motor weakness or of sensory disturbance. The hand, which at first felt "dead," had been paresthetic since the injury. He had never had any objective or subjective disturbances of sensation in the left lower limb or face.

When examined on Dec. 11, 1905, the movements of the left upper limb were awkward, although it could be moved freely at all parts and was not weak. He was unable to button his coat with his left hand alone when his eyes were closed, because of incoördination of the fingers, but could button it promptly with his right hand. The sense of position was greatly impaired in the fingers of his left hand, and he was usually unable to tell which finger was moved or when a finger was bent backward or forward. Stereognostic conception was also greatly impaired in his left hand, and usually he was unable to name any object placed in this hand if he did not see it. Occasionally if the object fell from the hand he was unaware of the loss. Sensations of touch, pain and temperature were diminished in the left hand, but not to the same degree as were the sense of position and stereognosis. He occasionally answered correctly when his left hand was touched or pricked with a pin, but usually his answers were uncertain and in marked contrast to the positiveness with which he replied to sensory tests of the right hand. The sensation of touch was a little less acute in the left hand than in the left arm above the elbow. Pain sensation was less altered than tactile sensation, and temperature sensations for both cold and warmth were more nearly equal in the two upper extremities. The spacing sense was also greatly altered in the left hand, and he could not tell whether the thumb and first finger were near together or far apart. In the right hand he could tell whether the thumb and first finger were one or two inches apart. Sensations on the chest seemed to be the same on the two sides.

The left lower limb was not affected. His answers to sensory stimuli were always correct and prompt. He recognized at once any movement of the toes and the direction in which they were moved. The limb was not weak. The patellar reflexes were not prompt. Sensation in the left side of the face appeared to be entirely normal, and the right side of the body was not affected. Hemianopsia was not present.

The case, according to the writer of the paper, seemed to indicate that the sensory centre for the upper limb was distinct from those for the face and lower limb.

When this patient was examined by one of us (Dr. Weisenburg) on Feb. 19, 1906, he was able to recognize a knife between the thumb and forefinger of the left hand, but was not able to do so with the other fingers. He was also able to recognize properly a coin, as a quarter, but in a few minutes his ability to recognize objects placed between his thumb and forefinger was not so good. Sensation for touch and pain was better on the skin over the thumb and forefinger than over the ulnar part of the hand. This difference in sensation between the radial and ulnar portions of the limb was also apparent on the skin covering the forearm up to the elbow, this differentiation not being apparent above this point. It seemed as if touch and pain were better recognized as the radial side of the hand and forearm was approached.

The sense of position was lost in the three ulnar fingers, impaired in the forefinger, and about normal in the thumb. The same could be said of the sense of pressure, the sense of localization and the sense of movement; in other words, the sense of pressure, of localization, of position and of movement were all better recognized as the radial side of the hand was approached. These different perceptions were lost or almost entirely lost in the two ulnar fingers, appreciated in the middle finger, better appreciated in the forefinger, and almost normally appreciated in the thumb. Bone sense, or that sense which is obtained by touching the bony parts with a vibratory tuning fork, was similarly better recognized as the radial side of the hand was approached. Repeated subsequent examinations invariably demonstrated the above facts. The ability to recognize objects between the thumb and forefinger was sometimes quite marked, and again the patient was barely able to recognize familiar objects.

Considerable ataxia was present in the finger to nose test, and this was more marked when he was told to place the ulnar fingers to the nose than when the other fingers were used. He complained continuously of a numb "breaking" feeling in his left hand, and also that he was very susceptible to temperature changes. When it was cold or warm his hand responded with extreme sensitiveness to changes in the weather from warm to cold or the reverse.

Subsequent examinations for sensation developed the interesting fact that touch sensation was altered more in the distal part than in the proximal parts of the fingers and that no difference in appreciation between the flexor and extensor surfaces of the hand existed. Touch sensation on the dorsum of the hand, however, was better appreciated as the thumb was approached. Sensation for pain was also more disturbed in the distal parts than in the proximal portions, but was distinctly better appreciated on the flexor surface of the hand than on the extensor surface. Different tests for temperature sensation did not seem to demonstrate any alterations from the normal. Applications of faradic electricity were much better appreciated on the palmar surface than on the extensor surface.

In one examination when the relaxation of the left hand was almost perfect it seemed as if the loss of the sense of position was more marked when the fingers were bent backward, that is, to the extensor side, than when they were bent forward to the palmar. This observation, however, was only made once. It may be said in passing that it is most difficult to obtain complete relaxation of the hand, and it is only when this is fully obtained, that the test for the sense of position is of positive value. It is our practice when testing for the sense of position to grasp the patient's hand at the wrist and ask him to completely relax, so that the slightest voluntary attempt of the patient to move his hand can be appreciated by the examiner by the transmission of motion to the palpating hand.

With regard to other examinations it need only be said that Dr. Spiller's report as to the sensory conditions was fully confirmed.

Case 3.—*Apoplectic attack with left hemianesthesia, more marked in the upper extremity; later limitation of sensory losses to the left upper limb; still later touch and pain more disturbed in the distal than in the proximal portions of the fingers and hand; touch and pain also better recognized on the radial than towards the ulnar side of the hand; the sensations of pressure, localization, position and movement, and stereognostic conception better preserved in the thumb and forefinger than in the other fingers.*

This patient was exhibited by Dr. C. D. Camp before the April meeting of the Philadelphia Neurological Society. She was a woman, 43 years of age, who had had four children and four miscarriages, and had an alcoholic but no specific history. Eight days before her admission to the nervous wards of the Philadelphia General Hospital, April 17, 1906, where she was under the care of Dr. J. H. Lloyd, she became excited, ran a short distance, sat down and immediately afterwards, trying to get up, fell, owing to weakness of the left side. She was not unconscious, but had a "peculiar" feeling in the entire left half of the body.

When examined by Dr. Camp on her admission the patient did not manifest any motor weakness in any portion of the body. She had no ocular nor facial palsies, and the limbs were moved equally and well in all directions. The tendon reflexes were, however, increased on the left side, and a distinct Babinski response was obtained on this side. The reflexes on the other side were normal. The patient had almost complete loss of sensation for touch and pain and temperature over the whole left half of the body, this not being limited, however, to the median line. The sensory changes even at this time were more marked in the upper limb than in the other parts. Examination of the visual fields showed no alterations. No symptoms of hysteria were present.

In a subsequent examination by Dr. Camp sensation was not as much disturbed as before. In the course of several weeks almost complete return of sensation in the left lower limb and over the chest, abdomen and face had taken place. The loss of sensation was now limited to the left upper limb. Dr. Camp also found considerable ataxia and complete astereognosis in this hand.

When examined by one of us (Dr. Weisenburg), about three weeks after the stroke, there was practically no involvement of the motor functions on the left side. The reflexes on this side were still somewhat exaggerated, and the Babinski response was prompt. Sensation in all forms was considerably disturbed in the left upper limb, and very little, if at all, in the other parts of the body. The senses of touch and of pain were more disturbed in the distal than in the proximal parts. A closer examination showed that the senses, both of touch and pain, were better recognized on the radial than on the ulnar side of the forearm. As in case 2, these two sensations were better recognized as the radial side of the hand was approached, both on the flexor and extensor surfaces.

The patient was unable to recognize clearly an object placed in any portion of the hand, but she was able to appreciate the smoothness or hardness or density or angularity of all objects with the thumb and forefinger, but could not do this with the other three fingers. Similarly numbers drawn on the palm seemed to be somewhat better, if at all, appreciated over the radial side of the hand than over the ulnar.

The senses of pressure, of localization, of position, of movement were all better recognized as the radial side of the hand was approached. This differentiation was as well marked as in case 2. Considerable ataxia was also present in the affected hand, and this seemed more marked when the ulnar fingers were approached to the nose than when the index finger was used in the test.

Case 4.—Initial Jacksonian attack chiefly causing flexion and extension of the forearm; sudden loss of ability to extend the flexed index and middle fingers; two weeks later a similar transient affection of the ring and little fingers; paroxysmal paresthesia showing itself as a peculiar sensation passing along the outer or ulnar border of the arm and forearm; disappearance of the attacks in the ring and middle fingers in about four months; improvement for several months, then renewal of paresthesia now affecting the ulnar border of the forearm; inability to freely abduct the little finger independently of the ring finger; tremor and moderate ataxia of the right upper extremity as tested by index and little finger to nose tests, also by writing and other methods; slight hypesthesia to touch over the ulnar border of hand as tested with cotton, this disappearing as tests continued; pressure sense retained everywhere; disappearance of sensory phenomena for two months followed by another paresthetic attack affecting the mid dorsum of the hand, the entire index finger, half of the middle finger, and distal phalanx of the ring finger; sudden transient loss of ability to use the middle finger; no objective sensory impairment, but persistence of former tremor and ataxia; no astereognosis.

A man over sixty years of age six years before coming under observation, first had an attack of jerking or twitching of the right arm of brief duration. The arm was adducted, and the forearm flexed, and while so held the movement affected the entire limb, although it chiefly showed itself in slight extension and flexion of the forearm.

Later he was treated for an abscess of the gall bladder, a condition which probably had no connection with his attack of local spasm.

For five years he remained in good health, until four weeks before the time when he first consulted one of us (Dr. Mills), when he suddenly lost the power, or apparently lost the power, to extend the flexed index and middle fingers, the other fingers being little if at all affected. Two weeks later he had a somewhat similar affection of the ring and little fingers. He could flex these, but for a few hours he could not extend them after they were flexed. This condition passed away during the night.

At this time and since at intervals he has suffered from a local paresthesia. He described this paresthesia as a peculiar sensation passing down the outer side of the upper arm to the ulnar border of the forearm. The patient had had no headache, vertigo, vomiting or other symptoms, being, except as above stated, in good health.

The patient was seen by Dr. Mills at intervals for four months, and then not for seven months. During the first three or four months the attacks of flexor spasm gradually disappeared. For the next six months his improvement continued, at least as regards the flexor spasm and paresthesia and the use of the fingers and hand. He became able to write, which he could not do before, so that he could attend to his own personal letters. It was, however, necessary for him to form his letters carefully, writing slowly.

After six months elapsed he again had a renewal of the paresthesia, which at this time chiefly affected the ulnar border of his right forearm. He had no return of the flexor spasm and inability to extend the fingers, but a peculiar condition of the ring and little fingers with regard to voluntary movement came on. He could not abduct the little finger of the right hand as he could that of the left, keeping the other three fingers in contact. He could, however, if the first fingers were held together by a rubber band or by the hand, abduct and adduct the little finger slowly, but not with as much freedom as the little finger of the other hand. When he did not hold the other fingers together and attempted to abduct the little finger, the ring finger invariably went with it as if the two fingers were glued together.

He had some tremor of the right upper extremity, especially of the hand; also a little of the left, but very slightly marked as compared with that of the right. Testing for ataxia of the upper extremity by the ordinary finger to nose method, some atactic tremor or ataxia of the right upper extremity, but none of the left, was found to be present. Testing by touching the nose with the little finger, while the index, middle and ring fingers were held together by a rubber band, the atactic tremor was about the same as when the test was made with the index finger. A similar test made on the left showed no tremor, or one so slight as to be scarcely noticeable.

No changes in sensation could be determined by coarse or comparatively coarse methods. The upper extremities were carefully tested by gently touching the parts with cotton. No loss of sensation could be detected by the most delicate methods in the left upper extremity, and none in the right except over a very limited area on the ulnar side of the right hand. A small area over the right hypothenar eminence was hypesthetic, or at least transiently hypesthetic, the diminution of sensation disappearing as repeated tests were made. These repeated tests showed that when he was first examined by delicate touches, the impairment went to the line of the metacarpophalangeal articulation of the little finger; after the tests were continued for a time he began to discriminate in this area as in other parts of the hand.

Testing him by Head's method for pressure sense it was retained for slight pressure in the tactile hypesthetic area. The pain and temperature senses were also retained, and no astereognosis of any part of the hand could be made out.

The knee-jerk on the right side was diminished; on the left it was distinctly plus. Achilles jerks were present and equal on both sides.

For about two months after the above phenomena were noted, the patient again improved in the use of his hand, gradually regaining power to separate his little from his ring finger in a nearly normal manner. The ataxia remained, but he improved in his ability to write. After the two months, however, he had another seizure which showed itself in a sensation of numbness or tingling, which starting near the middle line of the dorsum of the hand, passed down, enveloping the index finger, the middle finger from its tip to about the second phalangeal articulation, and the distal phalanx of the ring finger. The thumb and other parts of the fingers and the hand remained normal as to sensation. This paresthesia remained, and about two days later his middle finger suddenly became weak so that objects could not be held by it. No paresthesia had returned in the little finger and ring finger and ulnar border of the hand and forearm. The little finger could now be separated volitionally from the ring finger, although this, as other movements of the fingers, was awkwardly performed. He still had ataxia or atactic tremor in the upper extremity, especially showing itself in the hand and finger tests. He wrote his letters well, but with difficulty and rather painful slowness.

The patient called attention to an interesting fact which illustrated the difference between the control of the little finger of the right or affected limb and that of the left. He could insert the little finger of the left hand into the ear and manipulate it without the slightest difficulty, but he always had difficulty in inserting the finger of the right hand into the ear, although when it was once placed in this position he could move it around apparently with the same force and ease as the finger of the other hand.

Careful examination for objective impairment of sensation showed no loss, even to light touches, and no errors of location. His chief affection of the hand and fingers seemed to be, as it had always been, paresthetic and ataxic.

These four cases show a few points of great interest in connection with the subject of our paper. With regard to the positions of the lesions, as necropsy was obtained in only one case, of course nothing that is absolute can be said. In the one case with necropsy, the lesion destructive of the cortex and subcortex, was almost entirely in the postcentral and sub-parietal convolutions, only invading precentrally to a slight extent in one position. In the second case, first recorded by Dr. Spiller, the presumption is in favor of a lesion posterior to the central fissure, and this is true also of the third. In the fourth case, presuming it to be due to a cortical cerebral lesion, this is probably situated in the postcentral convolution, invading somewhat precentrally and posteriorly towards the sub-parietal region.

In the four cases the tendency was shown by the sensory disorders to select the ulnar or the radial side of the hand. In three of them the impairment of sensation, and the astereognosis were more persistent and decided in the middle, ring and small fingers and the ulnar portions of the hand. The thumb and index fingers were the first to improve and the last to succumb to persistent sensory disorder.

In all of the cases touch and pain senses were more disturbed distally than proximally in the fingers and hand.

In the first three of the four cases the sensations of touch and pain were more disturbed on the extensor or dorsal surface of the hand than on the flexor or palmar surface. This is an observation, which so far as we knew, at the time of the examination, had not been previously made.

In one of the cases (case 2) when the hand and forearm were totally relaxed, the patient had not the sensation of position and movement when the fingers were bent outward (extended), although he recognized position and movement when the fingers were bent inward (flexed). This is also, so far as we know, an observation not before made.

In the fourth case, which is one of great interest, the diagnosis of a cortical lesion, largely parietal, may of course be questioned, but a thorough consideration of the mode in which the sensory and paretic attacks in the upper extremity occurred, the persistence of ataxia in this extremity, although this was not marked, and the absence of positive symptoms which might relegate the case to the cerebellum, spinal cord or periphery would seem to make the diagnosis of a cerebral lesion or condition necessary. One of the most interesting points in this case was the absence of astereognosis, although ataxia was present and persistent, and paresthetic attacks recurred. The case lends some support to the view of the authors that the stereognostic zone is independent of the areas both of cutaneous and muscular sensibility, and also of the motor area.

It might be worth while in this connection to say a few words about the question of the existence of separate stereognostic and sensory areas from the standpoint of the development of function in the individual. Some recorded observations have shown that in children up to a certain age, while the sensations of touch, pain and temperature, are evidently recognized, topognosis, or the sense of location, stereognosis, and to some extent the musculo-arthroidal sense are wanting. These functions and their anatomical substrata develop as the infant becomes the child and the child the young adult. These facts lend support to the view taken by the writers that the localization of cutaneous sensibility is close to the motor zone, while the musculo-arthroidal sense and stereognostic conception are probably, as would be expected, in the concrete memory field or posterior association region or closely adjoining this region.

It is noteworthy in our four personal observations, in several of the nine observations collected by us, and also in the cases recorded by Russell and Horsley, to which attention will be presently called, that the impairment or loss of sensation in cases remaining under observation was invariably more persistent (unless the entire hand remained anesthetic), in the ulnar or postaxial portion of the limb. This is an observation of interest and one calling for explanation. It is probable that this lies at least in part in the fact that the cortical centres, sensory, stereognostic and motor, for those functions which are most frequently active in the individual have larger areas of representation, and that these are more deeply organized.

The earlier return of sensation or its greater persistence in flexor or palmar surface of the fingers and hand, and the more pronounced and persistent loss of the sense of position and movement in extension have a similar explanation.

The second proposition of this paper is that every muscle or group of muscles producing movement or movements which are represented by separate centres in the cortex is topographically related to a segment of the skin, which has also a definite cortical centre, this centre being correlated anatomically and functionally with the motor centre.

We believe that cases of limited sensory disorder due to lesions of the cerebral cortex or subcortex can be differentiated from the sensory affections of spinal, neural and hysterical origin, and also from anesthesias due to lesions of the thalamus and internal capsule, although this differentiation must, in some instances at least, be made by a study of concomitant clinical phenomena.

Some experiments in hypnotism may give a clue or a partial clue to the manner in which the cutaneous periphery is cortically represented and peripherally correlated to the musculo-arthroidal apparatus. To illustrate our meaning we might cite the following quotation from Heidenhain:

"Stimulation of different parts of the skin of the trunk constantly produces localized reflex movements; in the determination of these Dr. Born has kindly assisted me.

"Gently stroking the skin of the back at the sides of the spinal processes of the upper dorsal vertebræ causes elevation of the arms, with simultaneous slight flexion, so that the hands tend to meet above the head.

"Stimulation over lower dorsal vertebræ produced contraction of latissimus dorsi and rhomboidei, with resulting powerful backward movement of both arms and simultaneous flexion.

"Stimulation over the last dorsal and first lumbar vertebræ caused tonic contraction of the whole erector spinæ, with simultaneous elevation of the ribs (levatores costarum, intercostales) without accompanying contraction of the diaphragm, and hence passive sinking in of the abdominal muscles.

"Stimulation over the lower lumbar vertebræ and sacral region, the person being seated, caused contraction of flexors of leg, then of the ileo-psoas, and hence, the thigh being fixed owing to the sitting posture, the trunk was drawn down towards the thigh.

"Stimulation of the skin near the sternum: strong contraction of the pectoralis major, so that the arm was drawn to thorax; simultaneous stimulation of the extensors of arm.

"These reflex movements, which depend on the spinal cord and the medulla oblongata, represent a new series of phenomena in hypnotized persons, for previously only imitation movements, or such movements as had been passively induced by the operator, were known.

"It is certain that methodical investigation of the whole surface of the body would lead to the discovery of many more reflex relations."[14]

It will be seen in these experiments that the portions of the skin on which the stroking experiments were made were usually topographically correlated to the muscles or to some portions of the muscles through the instrumentality of which the movements resulting were performed.

We are not certain as to the exact state of the central nervous system during the existence of hypnosis. It is generally believed, however, that higher levels of the nervous system are in abeyance, that the activity of certain cortical cells is for the time being inhibited. The hypnotized subject is more or less lethargic and anesthetic because of the withdrawal through suggestion of the centres concerned with sensory and other forms of recognition. Persistent stimulation of certain areas of the skin unlooses the inhibited cerebral sensory centres and allows the cerebral reflex arc to be completed, the movements resulting being represented in segments of the spinal cord and re-represented in the cortex by cortical motor centres which are correlated to the sensory centres which have been called into action.

It is not probable that the areas of the skin which are separately represented in the cortex are in every instance exactly over the muscles, the cortical centres for whose movements are correlated to the cortical sensory areas, but skin and muscles, sometimes at least, bear this somewhat exact relation to each other; in other instances it may be that the cutaneous zone is related to certain portions of the muscles (as to their origins or insertions) concerned in the movements elicited. We do not know the exact topographical relations of correlated areas of the skin and muscular groups, but that they bear some relation like that above suggested, cannot be doubted.

To make our view as clear as possible we might cite some illustrations. The muscles performing certain very specialized movements, like that of flexion or of extension of the index finger, of adduction of the thumb, of ulnar extension of the hand at the wrist, or of flexion of the forearm at the elbow, have certain topographical relations with cutaneous areas. For the most part these cutaneous areas are over the muscles, or over the muscles, tendons and joints, concerned in the performance of the specialized movements. These cutaneous sensory areas are separately represented in the cortex, and the separate sensory areas of the cortex in turn are anatomically and functionally correlated with cortical motor centres.

The above views were presented by one of us (Dr. Mills) at the meeting of the American Neurological Association in St. Louis in September, 1904, and were prepared for publication in the present paper before the appearance of the paper by Russell and Horsley, to which attention will be presently called in detail. In a recent paper by one of us[15] our views with regard to the peripheral correlations between skin areas and muscular groups were presented as follows:

"In the periphery, segments of the skin are over or closely related topographically to the muscles producing movements which are represented in the motor cortex by centres which are connected with cortical sensory centres representing these cutaneous segments or areas. The segment of the skin covering the muscles producing adduction of the thumb, for instance, is represented in the cortex by a centre which is distinct but neuronally associated with the cortical centre for this movement of the thumb."

It will be seen that to a certain extent this view is in accord with the theory of Russell and Horsley of spinal segmental rerepresentation in the cortex. Preaxial, postaxial and midaxial cutaneous areas in the upper limb, for instance, may contain within them cutaneous subareas, each of which is represented by a cortical centre, and each of which is more or less correlated in position and extent to a preaxial, postaxial or midaxial muscle or muscular group. It is probable, however, that the areas of the skin represented in the cortex do not arrange themselves in the well-defined strips which correspond with the segmental or nerve root distributions. We may eventually get the diagnostic clues which will enable us to separate the spinal, neural and cortical areas of anesthesia by studying the differences in their respective topographical zones in patients with cortical, spinal or neural lesions.

The paper by Russell and Horsley[16] is on the apparent rerepresentation in the cerebral cortex of the type of sensory representation as it exists in the spinal cord.

The authors first refer to the differing views regarding separate or identical sensory and motor representation, adhering to the view that the areas of cortical representation of motion and sensation, or at least tactility, are identical or coincident. They also apparently adhere to the view, now largely disproved, that sensation and motion are represented almost equally on both sides of the central fissure. Horsley, as indicated in this contribution, has for many years believed that the type of sensory cortical representation is segmental.

It has been pointed out at the beginning of this paper that one of us has held for many years to the view that the representation of cutaneous and muscular sensibility in the cortex is subdivided after the manner of motor representation, the areas of representation, motor and sensory, being not anatomically identical. It was held for instance, in 1895, that differentiated areas and subareas for sensation were present' in the cortex and that no part of the brain was more likely to contain these differentiated areas for sensation than the gyrus fornicatus, the hippocampal gyrus, the precuneus and the post-parietal convolutions.[17]

Neither of us sees any reason for changing the position taken, with the exception that we would now exclude from the region of cutaneous and muscular sensibility the hippocampal convolution and would include in it the postcentral convolution, and probably also the posterior and inferior portions of the paracentral lobule.

Russell and Horsley admit that the facts collected and the experimental investigations made which point to conjoint sensory and motor localization were largely, if not altogether, based upon an acceptation of the view that the motor cortex was post-Rolandic as well as pre-Rolandic. A view which they now admit is called into question by the researches of Campbell[18] and Brodman[19], although they fail to refer to the investigations of Grünbaum and

Sherrington[20] and the paper on cortical faradization of the human brain, published in this country by one of us and Dr. Frazier[21], and also to other American papers pointing to the sensory and stereognostic functions of the parietal cortex.

Discussing the question of separate motor and sensory localization, Russell and Horsley say "that the view has appeared to them to be contrary to the evolution of the nervous system, since from the point of view of function, every part of the central projection apparatus must be sensori-motor, and from the morphological standpoint, all the homologies of the structure of the pallium compared with that of the lower nerve centres establish the same principle."

This reasoning does not appeal to us, for while it is true that sensation and motion are always represented in a complete reflex arc, spinal or cerebral, it does not follow that each of these functions is represented equally or in the same manner in the same part of this arc. While it is also true that in the lower forms of animal life an afferent fibre, a nerve cell, and an efferent fibre represent the completed nervous system, in the differentiation of the nervous system, as evolution proceeds, such readjustments and intercalations take place that sensory and motor centres become separated in the spinal cord at basal levels of the brain and in the cortex. The most reasonable view, as well as that which we believe is supported by carefully sifted facts, is that the correlated sensory and motor areas are in distinct, although it may be in adjacent portions of the cerebral surface. This is in accordance with the usual method of anatomical and morphological development. As centres and areas are added in connection with the development of higher and higher functions, the additions are made by surface expansion rather than by superimposition of layers. The convoluted cerebral surface assumes its configuration in obedience to this law of surface expansion and elaboration to accommodate centres endowed with different functions.

Russell and Horsley (always taking for granted that the cortex is sensori-motor and on both sides of the central fissure) show that the sort of sensation disturbed in the experiments in cases to which they refer was (1) slight tactility; (2) topognosis; (3) general orientation of the paretic part; (4) occasional pain. By topognosis is meant false localization of the spot touched. They found that this disturbance of sensation was in the direction of proximality; in other words, the point indicated was nearer the body than that absolutely touched. The error was regarded as segmental. In a case of severe or extensive cortical lesion the patient, when touched lightly on a terminal phalanx, indicated a spot on the dorsum of the metacarpus, and in a less severe case on the next phalanx or the next but one.

We are distinctly in conflict with the view expressed in the paper under discussion that stereognosis is represented all over the motor cortex. We believe that this function has a separate cortical habitation. One of us, and others in this country and in Germany, have published facts which seem to us convincing as to the cortical area of stereognostic conception being postero-parietal in situation. Cases of cortical or cortico-subcortical paresis without astereognosis and cases of cerebral astereognosis without paresis are now on record.

We use the term stereognostic conception by preference, believing that this cerebral function or process in its typical form belongs in the field of concrete conceptual activity. The stereognostic region is a subarea of the concrete memory field.

The most interesting portion of the article by Russell and Horsley is that which relates to the apparent re-representation of the spinal cord metameric type of sensory topography in the cerebral pallium. The spinal segments or metameres, as is well known, are in direct relation with certain nerve roots, and these nerve roots supply the cutaneous periphery in a special manner which differs from the peripheral nerve distribution. Speaking generally, the nerve root distribution to the limbs, especially to the upper limbs, is in a series of longitudinal strips as shown in the well known diagrams of Edinger and others. Briefly stated, the view of Russell and Horsley is that these strips of skin represented by the nerve roots and spinal segments or metameres are re-represented in the cerebral cortex.

Many years since, one of us in an article on spinal localization called attention to the observations and work of Ross[23], Paterson[24], Herringham[25], Thorburn[26], and others in this field. Russell and Horsley refer especially to the observations of Ross and Paterson, and also to the later work of Grünbaum and Sherrington[27] and of Head.[28]

Ross introduced the terms preaxial and postaxial. The preaxial portion of a limb is the part situated on the internal or inferior aspect,—in the arm on the radial and in the leg on the tibial side; while the postaxial subdivision of the limb is situated posterior to the long axis,—in the arm on the ulnar and in the leg on the fibular side. The following quotation from the paper on spinal localization will serve to make the matter clear:

"Sensory segmental localization follows certain laws. If the upper extremity, according to Ross, be placed in the embryological position—that is, with the thumb directed outward and upward, and palm forward—the preaxial border from the tip of the shoulder down to the metacarpophalangeal articulations of the index finger and thumb is supplied by the fifth cervical root, and the postaxial border, from the axilla to the finger-tips inclusive, is supplied by the humeral branch of the second, the first dorsal, and the eighth cervical nerves. Observations made in cases of disease of the cauda equina have also convinced Dr. Ross that if the lower extremities be also placed in the embryological or tailor position, the preaxial border is supplied by the cutaneous nerves of the four upper lumbar nerves, and the postaxial by the coccygeal and sacral sensory nerves. He has concluded also that the most distal parts of the preaxial border were supplied from the lower of the four lumbar nerves, and of the postaxial border by the higher sacral nerves.

"The chief law of sensory distribution, as worked out by Herringham and adopted by Ross, is as follows:

"A. Of two spots on the skin, that which is nearer the preaxial border tends to be supplied by the higher nerve.

"B. Of two spots in the preaxial area, the lower tends to be supplied by the lower nerve, and of two spots in the postaxial area, the lower tends to be supplied by the higher nerve."

Russell and Horsley, also following Ross, define the terms preaxial and postaxial particularly as applied to the upper limbs, showing that the preaxial portion of the limb is supplied by the fifth, sixth and seventh cervical nerves, and the postaxial by the eighth cervical, and the first and second dorsal or thoracic nerves. They believe also that the central line or axis of the limb probably has a special morphological significance, and a special cortical representation.

As evidence of this they present two interesting cases; one unreported case of Dr. James Taylor and the other of Dr. T. Grainger Stewart[29], recorded in 1894.

In Taylor's case the aura of the Jacksonian attacks first began with sensations of pins and needles in the third and fourth fingers of the left hand. In this case a subcortical tumor was removed from beneath the postcentral convolution and forward to the island of Reil. Seventy-three days after operation, examination by medium pressure with pin point showed anesthesia of the dorsum of the hand and proximal errors towards the mid axis.

In Dr. Stewart's case sensation was disturbed in the entire upper extremity, except in a narrow strip in about the mid axis of the dorsal and ventral surfaces. Russell and Horsley hold that these cases and others of a similar character support the inference which naturally arises from the acceptance of preaxial and postaxial representation in the pallium, and that the mid axis of the limb is also there represented.

Russell and Horsley cite the notes of five cases bearing upon the question of preaxial and postaxial subdivisional representation in the cortex. We append the notes of these cases, largely in the language of the writers, simply somewhat condensing them and here and there changing the nomenclature to correspond to that used in this paper.

Their first case, one of Dr. Beevor's, was a man 42 years old, with pachymeningitis involving the right cortex over an area posterior to the central fissure and above the Sylvian fissure, the area including the lower half of the postcentral and the whole of the inferior parietal gyres. "The postero-inferior angle of the part removed included both sides of the posterior third of the Sylvian fissure. The depth of the incision was about 2 cm., *i.e.*, the floor of the lesion was composed of corona radiata.

A. Before operation. Slight diminution of sensibility to pain over hand and forearm to elbow, to camel-hair touch on fingers of the left hand. Loss of sense of position in fourth and fifth fingers, marked astereognosis. Postaxial error of localization on dorsum of middle, ring and little fingers of the left hand. On the palmar surface there was no error. On the dorsum of the left hand and wrist the topognostic error was proximal. The errors were always much greater after a fit, and gradually diminished during the succeeding ten to fourteen days.

B. After operation. (1) Immediately after operation, complete hemianesthesia of tactility and thermal sense, hemianalgesia of face, upper limb and trunk, relative on lower limb, hemianopsia, hemimotor paralysis of arm and face, slightly of leg.

(2) Fourteen days after operation, analgesia less marked. Visual fields restored; shoulder and elbow movements restored; also slight power of flexion and extension of the wrist and fingers. Complete loss of sense of position of the upper limb.

(3) Twenty-eight days after operation. Returning postaxial estimation of position of hand.

The second case of Russell and Horsley (case of Dr. Risien Russell) is recorded as follows: M. B., 40 years old. Glioma (mass removed 5 cm. longitudinal axis, 4 cm. frontal axis, 3 cm. vertical depth) situated immediately subcortical to the junction of the leg and arm centres in left hemisphere. The lesion left by the removal of the growth involved both the central ascending gyres; and extended into the corona radiata to a depth of from 3 to 5 cm.

A. Before operation. Soon after a Jacksonian fit, beginning in the foot and involving whole side and limbs, there was present in the right hand definite atopognosis (proximal error) astereognosis and hemiparesis of right side.

B. After operation. (1) Thirteen weeks after operation. Marked postaxial localization of all light touches on dorsum of digits, as well as topognostic proximal error.

(2) Sixteen weeks after operation. No analgesia, no loss of pain or temperature sense. Defective sense of light touches on dorsum of digits, normal on forearm, very marked proximal atopognostic error on digits and distal error on dorsum of carpus and matacarpus. The error was preaxial on the fourth and fifth digits, and postaxial on the first and second digits. When tested with Horsley's divided plate the postaxial error between the two index fingers was extremely marked.

The third case of the series was one of Sir Victor Horsley. J. C., male, age 56 years. Operation, October 21, 1905. A small myxoma about 3 cm. in diameter situated in the middle third of ascending parietal gyrus was found. There was considerable amount of softening in the corona radiata beneath the cortex, which certainly involved the fibres of the ascending frontal as well as the ascending parietal gyrus and probably also the fibres of the paracentral lobule.

A. Before operation. Hemiparesis of upper limb. Definite atopognosis proximal, in right hand.

B. Twenty-four days after operation. Anesthesia to light cotton wool touches all over dorsum of all digits, pain and temperature sense normal.

The topognostic error was preaxial on the dorsum of the digits as well as proximal. The latter error occurred as far as the carpus.

The fourth case was also one of Sir Victor Horsley's. G. P., male, aged 62 years. A small glioma occupying the breadth of the right ascending frontal gyrus and extending to the anterior wall of the fissure of Rolando. The corona radiata was compressed slightly, but nowhere softened. The lesion made by the extirpation of the tumor involved the anterior third of the width of the ascending parietal gyrus opposite the crater in the ascending frontal gyrus.

A. Before operation. Marked atopognosis in the left hand (dorsum of digits).

B. After operation. Marked proximal atopognostic error of all digits of left hand. Very marked postaxial error of the same digits.

The fifth case of Russell and Horsley was a patient of Dr. Aldren Turner. W. D., male, 22 years old. At autopsy (a) Small tubercle ¾ cm. in diameter growing from pia at junction of posterior part of second frontal, with ascending frontal in left hemisphere. (b) Similar tubercle 1½ cm. diameter in mid third of post central convolution on left hemisphere, and another of about the same size at extreme upper limit of post central convolution. A fourth in right hemisphere ¾ cm. in diameter in first frontal convolution.

Case of multiple lesions of the kinesthetic area.

Attacks of spasmodic twitchings in the fourth and fifth fingers of right hand, and simultaneously of eyelids.

Slight motor paresis of the fourth and fifth digits.

Slight anesthesia to light touches on the fourth and fifth digits.

Error of topognosis very slightly distal and preaxial on the fourth and fifth digits.

In the first case of Russell and Horsley, the observations with regard to the radial or preaxial portion of the limb are similar to those recorded by us in our cases, and also by some of the observers cited by us. Russell and Horsley also note a fact to which we have directed attention in commenting on our own cases, that the errors of sensation were less marked on the palmar than on the dorsal surfaces. They also record the earlier preaxial or radial return of sensation and of stereognosis.

In the second case the distinction between postaxial and preaxial sensory disturbance is emphasized, and also between the dorsal and palmar recognition. In this case, as in the others, the differences between proximality and distality in the areas noted are given. In cases studied by us we have not made any observations on this interesting point. In the fourth of our original cases, an effort was made to determine whether there was any difference proximally and distally without any result, although as will be recalled, the impairment of sensation disappeared as the ulnar or preaxial border of the hand was receded from. In this case the impairment of tactile sensation was very slight. In two other cases some experiments were made as to proximal or distal errors, but without result. In the third case of Russell and Horsley preaxial and dorsal impairment was greater, and proximal errors prevailed as in the other cases.

In the fourth case the preponderance of sensory impairment was postaxial, dorsal and proximal.

In the fifth case the anesthesia was more marked postaxially, that is, in the fourth and fifth fingers, and in these fingers it was preaxial and distal.

NOTE.—While this paper is passing through the press, a case illustrating some of the points discussed in it, especially the existence of a separate cortical area for stereognosis, and the subdivision of this area, has come under our notice. This patient was under the care of Dr. R. S. Dorsett, of Philadelphia, with whom the patient was seen in consultation by Dr. Weisenburg, and subsequently by Dr. Mills after the admission of the patient to the hospital of the University of Pennsylvania.

The patient, a man thirty-two years old, with no history either of alcoholism or syphilis, was perfectly well until three weeks before coming under observation, when he awoke during the night with a pain in the left side of the back of the head and in the same side of the neck, this pain disappearing the following morning. Two days after this, he began to complain of a numb, dead feeling in his left arm, followed in a day by similar sensations over the left chest and abdomen and the left leg. These sensations have persisted. About two weeks after the onset of these sensations he noticed that the grip in his left hand was not as good as before when his attention and eyes were directed elsewhere than to the object grasped. He has never had headache, nausea, vomiting or any disturbance in his eyes.

When examined his eyes and cranial nerves were found to be in a normal condition. The grip of the left hand, when his attention was called away, was not as good as when he was looking directly at his hand, in which case it was normal. The left leg, like the face and arm, showed no weakness. The reflexes were somewhat prompt, especially on the left side, but no Babinski was present. Sensation for touch, pain and temperature, and bone sensation were normal over the left side and everywhere. The senses of position and movement were lost or greatly impaired in the fingers of the left hand, the loss becoming less as the thumb and forefinger were approached. To a less extent the sense of location was disturbed; more so, as the radial side of the hand was approached. The sense of pressure was normal. He could not recognize any object placed in or manipulated by his left hand, the astereognosis being absolute. The hardness or softness of an object, or its surface contour could however be recognized, but only by the tips of his forefinger and thumb, especially the latter.

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